Surface Wave Processes on the Continental Shelf and Beach

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LONG-TERM GOALS

There is a growing need for surface wave information on the continental shelf and beach to estimate sea state, and to provide input for models of currents, sediment transport, radar backscatter and aerosol generation. While surface wave spectra in the open ocean evolve slowly over distances of O(100-1000 km), wave properties on the continental shelf and beach are highly variable (typical length scales of 0.1-10 km) owing to a variety of topographic effects (e.g., shoaling, refraction, scattering) and strongly enhanced nonlinear interactions and dissipation. The long-term goal of this research is to develop a better understanding of the physical processes that affect the generation, propagation and dissipation of surface waves in shallow coastal waters, and improve the accuracy of models that predict the transformation of wave properties across the shelf and beach.

OBJECTIVES

- predict accurately the nonlinear shoaling transformation of ocean surface waves on beaches including the excitation of infragravity motions
- evaluate models for wave dissipation by bottom friction
- determine the scattering effects of resonant wave-wave and wave-bottom interactions on the evolution of wind sea and swell spectra on the continental shelf
- improve the representation of source terms in operational wave prediction models
- determine the importance of wave reflection and trapping by steep submarine topography

APPROACH

A combination of theory, analytical and numerical models, and field experiments is used to investigate the physical processes that affect surface wave properties on the continental shelf and beach. The transformation of wave spectra is predicted with models that include the effects of refraction, scattering by wave-wave and wave-bottom interactions, and parameterizations of bottom friction, and wave breaking. Extensive field data sets were collected in recent ONR experiments off North Carolina (DUCK94, SandyDuck, SHOWEX) and California (NCEX) to test these models in a range of coastal environments. A new experiment (SAX04/Ripples) in progress on the Florida

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Gulf coast is focused on the complex interactions between waves and small-scale seafloor morphology. Analysis techniques applied to the measurements include various inverse methods to extract directional and wavenumber properties from array cross-spectra, bispectral and trispectral analysis to detect nonlinear coupling, as well as standard statistical methods to determine empirical relationships between observed variables.

WORK COMPLETED

During September-December 2003 a large array of wave- and current measuring instruments was deployed offshore of La Jolla, California, as part of the Nearshore Canyon Experiment (NCEX), funded jointly by ONR and NSF. The field site is characterized by two submarine canyons, the larger and deeper La Jolla Canyon branches out to the north-east into a narrow trench, called Scripps Canyon (Figure 1). The heads of both canyons are within a few hundred meters of the shoreline resulting in extreme topographic effects on the relatively long wavelength Pacific swells observed on nearby beaches. In collaboration with William O'Reilly (SIO) and Steve Lentz (WHOI), I deployed a large array of instruments in depths ranging from about 10-100 m (Figure 1). This array includes 7 Datawell Directional Waverider Buoys, 17 bottom pressure recorders, 12 Nortek Vector pressure-velocity sensors and 7 current profilers.

Five directional wave buoys and four bottom pressure recorders were concentrated around the head of Scripps Canyon where the most severe topographic effects are expected. These instruments were placed as close as possible to the canyon walls while one buoy was moored directly over the canyon axis to obtain detailed measurements of the near field effects of the steep topography on the incident swell. A coherent linear array of 5 pressure gauges was positioned on the south side of the Scripps canyon head in a region that is almost completely sheltered by the submarine topography from direct swell arrivals (Figures 2 and 3, discussed below). The purpose of this array is to detect "indirect" swell arrivals resulting from topographic scattering effects as well as possible infragravity edge wave arrivals from more energetic surf zones to the north and south of the canyon head. An alongshore array of 12 Nortek Vector pressure-velocity (PUV) sensors was deployed along the 10 m depth contour inshore of Scripps Canyon (Figure 1). Several of these instrument sites also included a Nortek Aquadopp velocity profiler. This array forms the offshore extension of a massive surf zone array with similar instruments (not shown) deployed by Steve Elgar (WHOI) and Robert Guza (SIO). This region is of particular interest because the steep and shallow canyon head causes extreme alongshore variations in wave heights. The combined arrays will be used to test models for the shoaling transformation of waves and the associated nearshore circulation.

At the northern end of the NCEX site where the shelf is approximately alongshore uniform, a directional wave buoy, two RDI acoustic Doppler current profilers, and a bottom pressure recorder were deployed along a cross-shore transect (Figure 1). Additional instruments along the same transect in shallower water (not shown) were deployed by Britt Raubenheimer, Steve Elgar, and Robert Guza. The primary purpose of this transect is to extend our earlier studies of wave shoaling and inner shelf currents on the North Carolina shelf (Lentz et al., 1999; Herbers et al., 2003) to a narrower west coast shelf. Finally, 7 bottom pressure sensors were deployed in the region between Scripps and La Jolla canyons. The primary purpose of these sensors is to resolve complex infragravity seiches expected between the canyons (thesis work conducted by MIT/WHOI student J. Thomson) as well the refraction and focusing of swell by the two canyons.

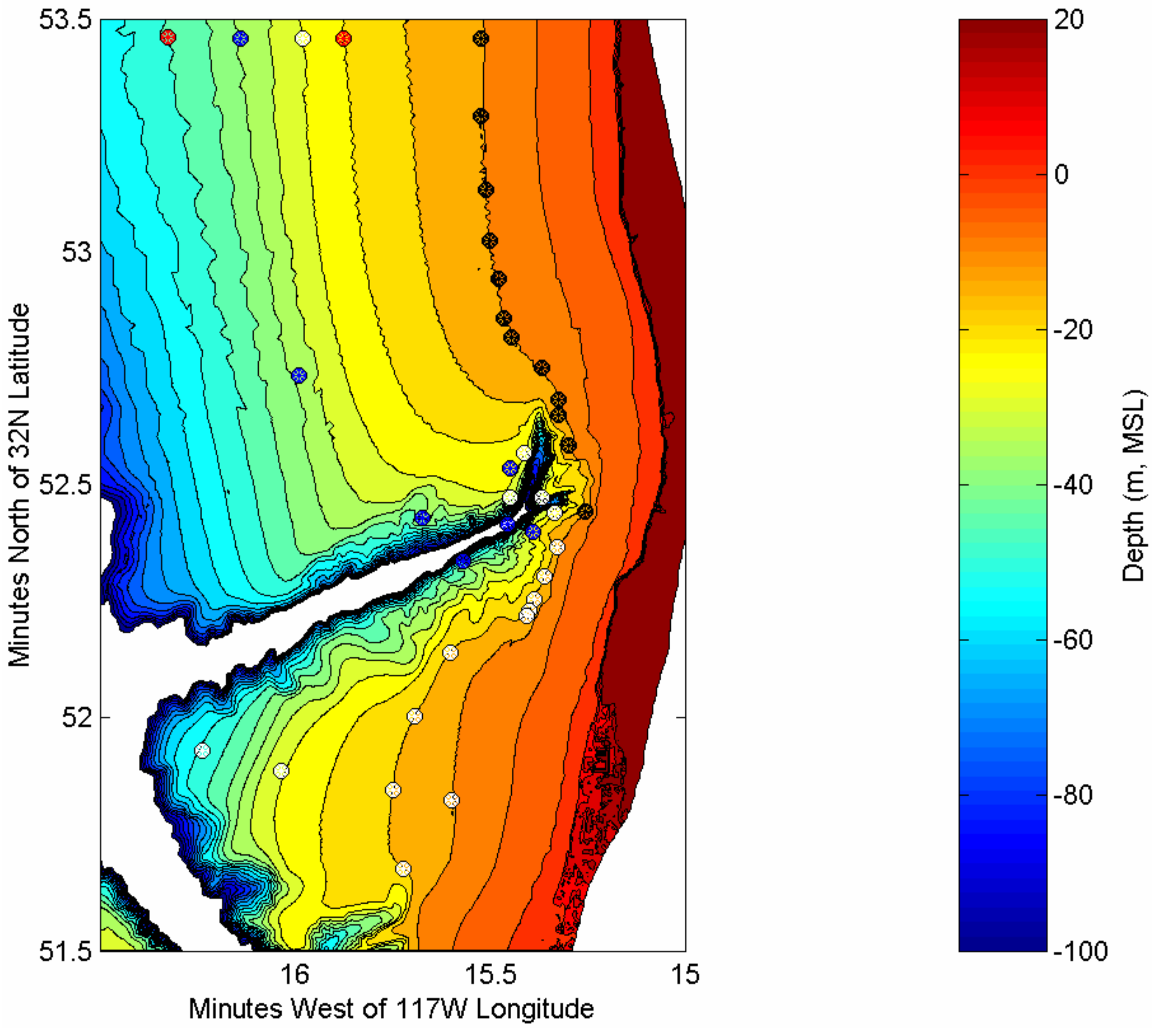

Figure 1. Plan view of instruments (circles) deployed during September 2003 (in collaboration with W. C. O'Reilly and S. J. Lentz) near La Jolla, California, as part of the Nearshore Canyon Experiment (NCEX). The array includes directional wave buoys (blue), bottom pressure recorders (white), pressure and current meters (black) and current profilers (red).

High quality measurements were collected at all 38 sites nearly continuously for 3 months (mid Sept-mid Dec 2003). During this time period numerous energetic, long period swell events were recorded originating from both southern and northern hemisphere storms.

RESULTS

Example observations that illustrate the strong topographic effects on long period swell are shown in Figure 2. Significant wave heights relative to the deep water value observed at an offshore buoy are compared at two pressure sensor sites located on the north and south side of the head of Scripps Canyon (right panel). Even though the alongshore separation of these two sensors is only about 200 m, the observed wave heights are radically different. South of the canyon observed wave heights usually vary between 5 and 35 % of the offshore wave height, and this strong attenuation appears to be insensitive to the incident wave direction. In contrast, north of the canyon the observed wave heights show a strong dependence on the incident wave direction with reductions in wave height (relative to deep water) for South swell and amplification for West swell.

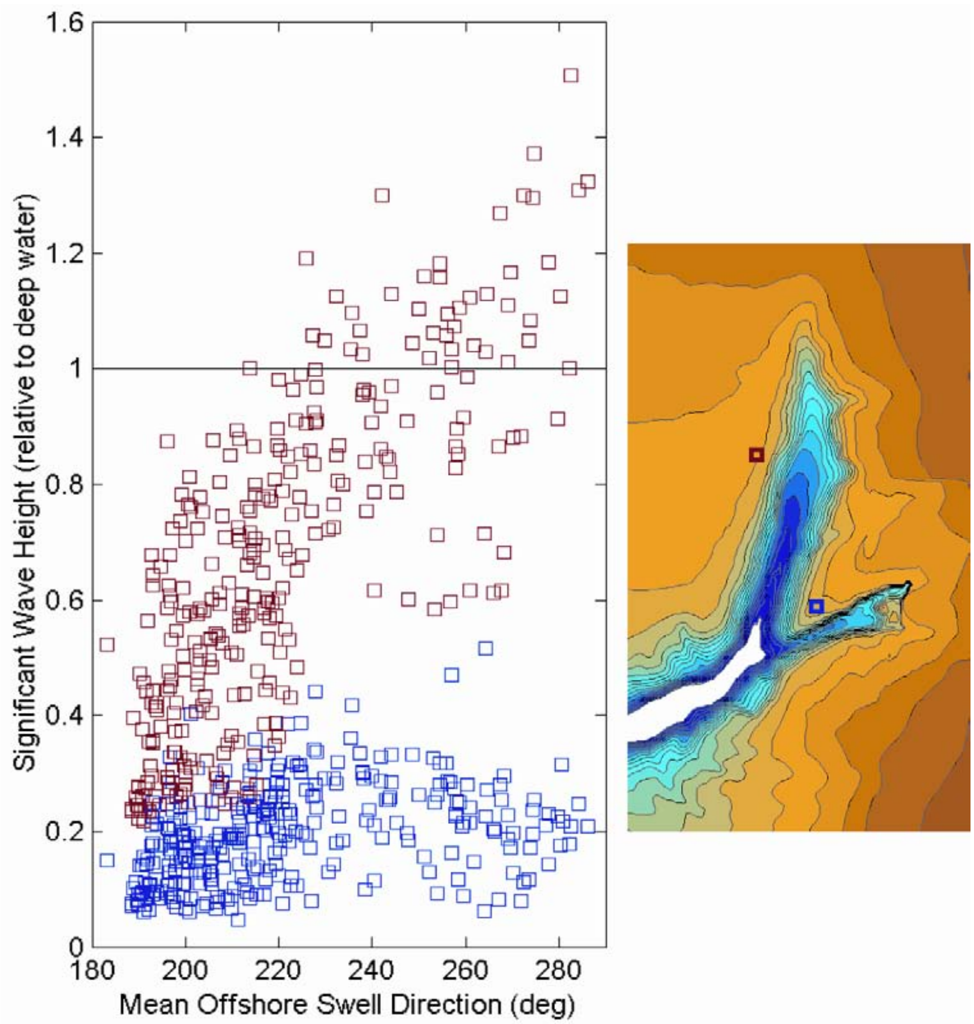

Figure 2. Wave height observations during NCEX at two pressure sensor sites near the head of Scripps Canyon (locations are indicated in the right panel). The significant wave heights (over the frequency range 0.04-0.10 Hz) are normalized by the offshore wave height (measured with the CDIP Outer Torrey Pines Buoy) and shown versus the deep water incident swell direction. Each symbol corresponds to a two-hour data record with a swell peak period of at least 14 sec.

These observations can be explained qualitatively by the effect of refraction over the complex bathymetry (Munk and Traylor, 1947). For waves arriving from southerly directions, propagating along the shelf in deep water, refraction over the continental shelf causes attenuation at all nearshore sites. Waves arriving from westerly directions, approximately normal to the coastline, are less affected by the continental shelf but experience severe refraction over the canyons. Ray computations that describe the propagation paths of a typical swell with a period of 16 sec and arriving from 280 degrees are shown in Figure 4. The ray trajectories are deflected by Scripps Canyon, effectively blocking any direct swell arrivals on the south side of the canyon, consistent with the observed low wave heights (Figure 3). North of the canyon refraction theory predicts a crossing ray pattern of waves propagating across the shelf and waves deflected by Scripps canyon, consistent with the observed wave height amplification (Figure 2) and crossing wave trains frequently observed at Black's Beach.

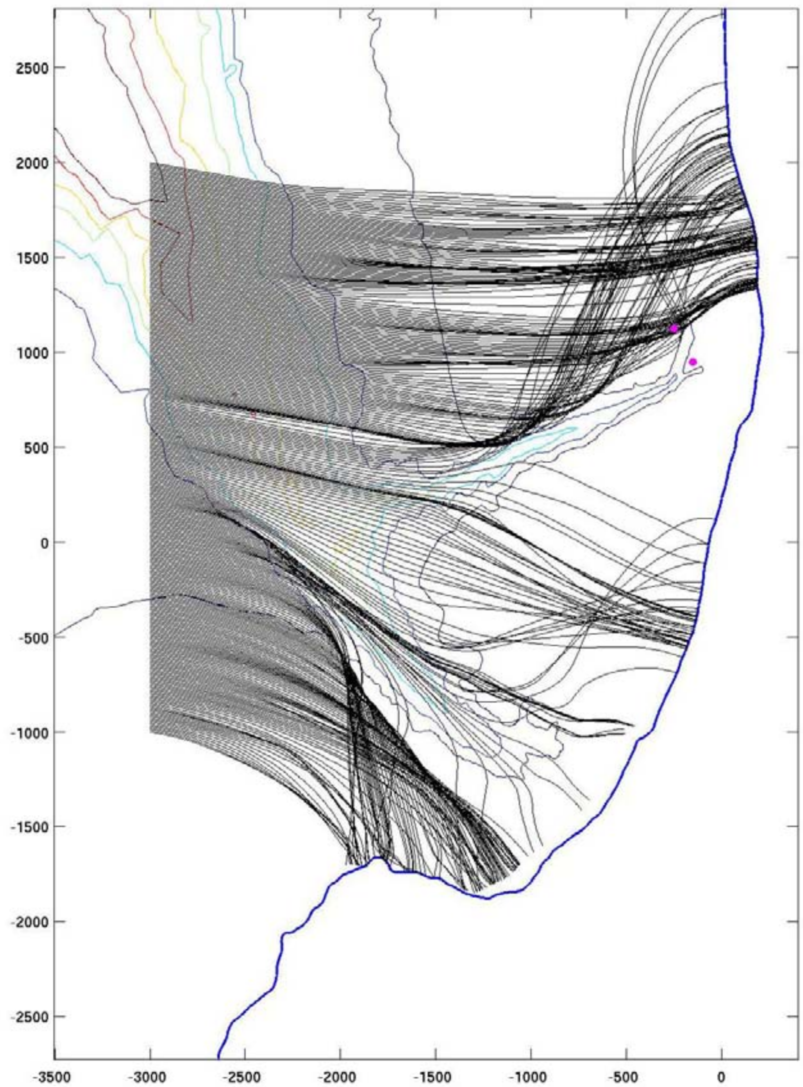

Figure 3. Ray trajectories for 16 sec swell arriving from 280 degrees. Dots near the canyon head are locations of observations shown in Figure 2. The axes indicate distances in m.

IMPACT/APPLICATIONS

Abrupt shelf bathymetry can cause dramatic alongshore variations in waves, resulting in beaches with large waves located only a few hundred meters away from beaches with small waves. These along-coast changes in wave height and direction can force complicated circulation patterns, including alongshore flows that reverse direction across the surf zone and along the shoreline, and strong offshore-directed rip currents that may be an important mechanism for transport of water, sediment, and pollution between the surf zone and inner shelf. The NCEX experiment has produced the first comprehensive data set of these processes that will be used extensively to validate and advance nearshore prediction models.

RELATED PROJECTS

Results of this research are adapted and implemented in a comprehensive nearshore community model that is being developed under sponsorship of the National Oceanographic Partnership Program (NOPP) (Lead-PI: J. T. Kirby).

REFERENCES

Herbers, T. H. C., M. Orzech, S. Elgar, and R. T. Guza, Shoaling transformation of wave frequency-directional spectra, *J. Geophys. Res*., **108**(C1), 3013, doi:10.1029/2001JC001304, 2003.

Lentz, S., R. T. Guza, S. Elgar, F. Feddersen, and T. H. C. Herbers, Momentum balances on the North Carolina inner shelf, *J. Geophys. Res*., **104**(C8), 18205-18226, 1999.

Munk, W. H., and M. A. Traylor, Refraction of ocean waves: A process linking underwater topography to beach erosion. *J. Geology*, **LV**(1), 1-26, 1947.

PUBLICATIONS

Noyes, T. J., R. T. Guza, S. Elgar, and T. H. C. Herbers, Field observations of shear waves in the surf zone, *J. Geophys. Res*., **109**, C01031, doi:10.1029/2002JC001761, 2004. [published, refereed]

Ardhuin, F., and T. H. C. Herbers, Numerical and physical diffusion, Can wave prediction models resolve directional spread? *J. Atmos. Oceanic Technology.* [in press, refereed]

Sun, J., S. P. Burns, D. Vandemark, M. A. Donelan, L. Mahrt, T. L. Crawford, T. H. C. Herbers, G. H. Crescenti, and J. R. French, Measurement of directional wave spectra using aircraft laser altimeters, *J. Atmos. Oceanic Technology*. [in press, refereed]

Magne, R., F. Ardhuin, V. Rey, and T. H. C. Herbers, Topographical scattering of waves: A spectral approach, *J. Waterway, Port, Coastal, and Ocean Eng*. [submitted, refereed]

Sheremet, A., R. T. Guza, and T. H. C. Herbers, A new estimator for directional properties of nearshore waves, *J. Geophys. Res*. [submitted, refereed]

Noyes, T. J., R. T. Guza, F. Feddersen, S. Elgar, and T. H. C. Herbers, Model-data comparisons of shear waves in the nearshore, *J. Geophys. Res*. [submitted, refereed]